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VOL. III, No. 9

MARCH 1919

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ERRATA

Page 272, foot notes, for "kokgbu" read "kokubu"
„ 277, line 10 from bottom, for "o" read "of"
„ 283, „ 8 „ „ , „ "alumium" read "aluminium"

The Effect of an Electric Field on the Spectrum Lines of Hydrogen.

PART III.

By

Toshio Takamine and Noboru Kokubu.

(Received July 12, 1918.)

In earlier communications[1], one of the present writers in conjunction with Mr. Yoshida has reperted on the Stark effect on hydrogen lines examined by Lo Surdo's[2] method.

In the present experiment, the arrangement was essentially the same, excepting that a tantalum cathode was used instead of one of aluminium. This proved to be advantageous since the sputtering of the cathode was considerably decreased. Further, by reducing the pressure in the discharge tube until the end of the Crookes' dark space became quite indistinct, the maximum field strength ($E_{max.}$) was greatly increased. Assuming the proportionality between the amount of separation and the field strength, the exterpolated value of $E_{max.}$ was about 150000 volt/cm. The data given by Stark in the case of the "Grobzerlegung" of the hydrogen line H_γ were relied on as in our former experiments.

A. Balmer Lines.

(1) H_γ

One remarkable feature newly observed in the present experiment was the *shift* of the central line in the perpendicular component of H_γ in a strong electric field.

As shown in Fig. 1, Pl. II, the lowest portion of the said line is clearly bent toward the positive side. For reference, the light from a

1 Takamine and Yoshida, Mem. Coll. of Sci., Kyoto, **2**, 137, 321 (1917).

2 Lo Surdo, Rendiconti d. Lincei, **22**, 664 (1913).

hydrogen Geissler tube was projected on the slit afterwards without touching the spectrograph.

The amount of the shift was found to be about $+1$ Å at the field of 130000 volt/cm. Owing to the diffuseness of the outer components, accurate measurement with respect to the symmetry of separations was difficult, but the phenomenon evidently shows one-sided property of the central line.

In his monograph[1], Stark states that, with the arrangement used in his experiment, the position of the initial line cannot be accurately determined owing to the Doppler effect in canal rays. We think, the above cited shift of the H_γ line is free from the ambiguity of this kind.

In our recent study of the Stark effect on helium lines[2], an altogether similar feature was observed for the lines 4026 and 4388, belonging to the diffuse series of helium and parhelium. These lines corresponds to the same term number $n=5$ as the H_γ line.

The similarity in the appearance of the central *s*-component of H_γ and that of the helium line 4388 is shown in Fig. 2, Pl. II.

In a few cases, the shift of the central *s*-component was observed also for the line H_ε; but owing to the insufficient data, we mention it here only with reserve.

(2) H_α.

In the monograph of Stark, only 2 *p*- and 1 *s*-components are given for this line, but later[3], he observed 6 *p*- and 3 *s*-components. Using a 6 inch plane grating, mounted in Littrow type, photographs as shown in Fig. 3a and 3b, Pl. II, were obtained in the second order spectrum. The dispersion was about 18 Å per mm. at this line. Although much detail is lost in printing, we could distinguish 6 *p*- and 3 *s*-components just as noted by Stark.

B. Secondary Spectrum of Hydrogen.

In addition to the 43 affected lines previously reported by Takamine and Yoshida[4], and also by Nitta[5], we have found 11 more in the region below 4000 Å.

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1 Stark, Elektrische Spektralanalyse chemischer Atome. Leipzig, S. Hirzel (1914).

2 Takamine and Kokgbu, Mem. Coll. of Sci., Kyoto, 381 (1918).

3 Stark, Ann. Phys., 48, 183 (1915).

4 Takamine and Yoshida, loc. cit.

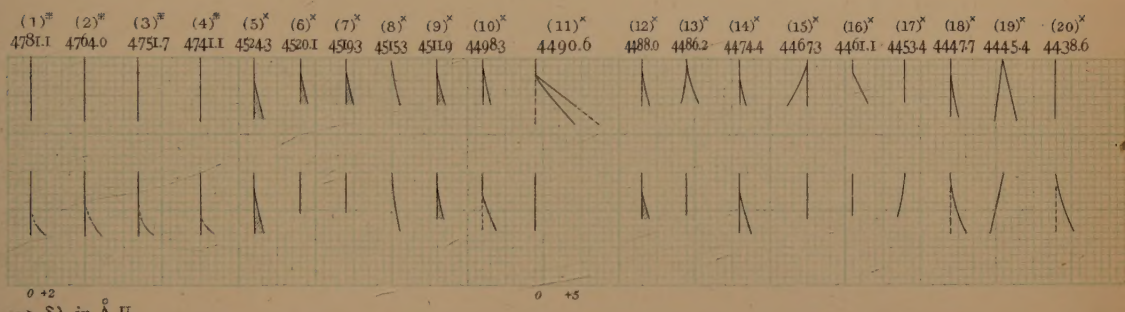
5 Nitta, Mem. Coll. of Sci., Kyoto, 2, 349 (1917).

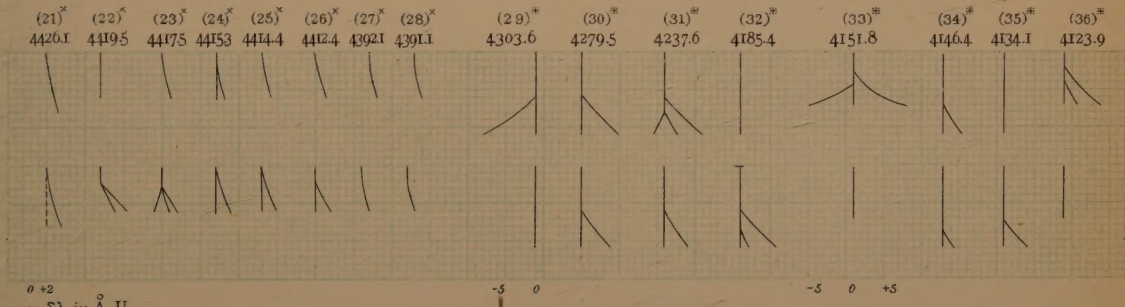
In order to facilitate a glance at the results hitherto obtained in our Institute, the diagrams including the former data are given in Pl. I.

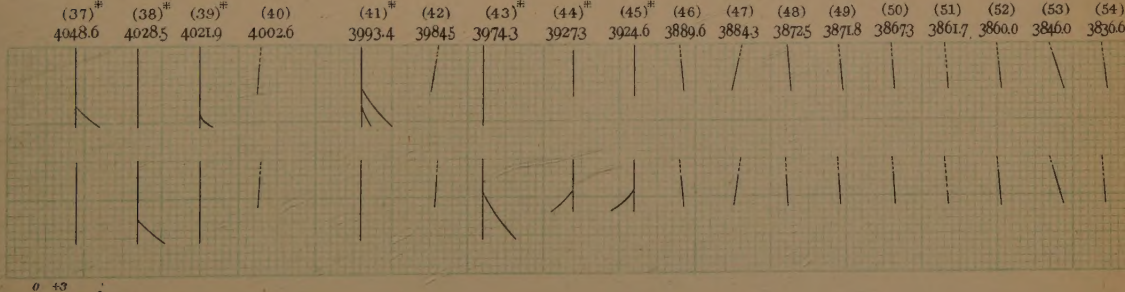
As noted by Stark[1], the great difference in the Stark effect on Balmer lines and on secondary lines seems to suggest that they are due to different sorts of carriers. It is remarkable that all the affected lines given in Pl. I are of rather weak intensity. In fact, with a dispersion sufficient for detecting a displacement of 0.3 or 0.4 Å, no influence of the electric field was observed for the group of strong lines 4634, 4632, 4583 and 4580, even in the strong field of 150000 volt/cm. In connection with this, it may be noted here that no electric effect was observed for the nitrogen bands in such a strong field.

In conclusion, the writers wish to express their thanks to Prof. Mizuno for the interests he has taken in the work.

1 Stark, Ann. d. Phys., **49**, 179 (1916).



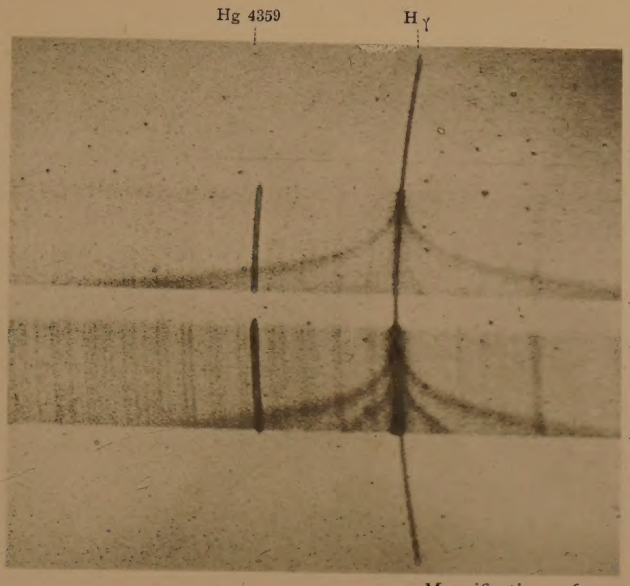




×---------- Takamine and Yoshida, Mem Coll. of Sci., Kyoto, 2, 137, 321 (1917).

*---------- Nitta, Mem. Coll. of Sci., Kyoto, 2, 349 (1917).

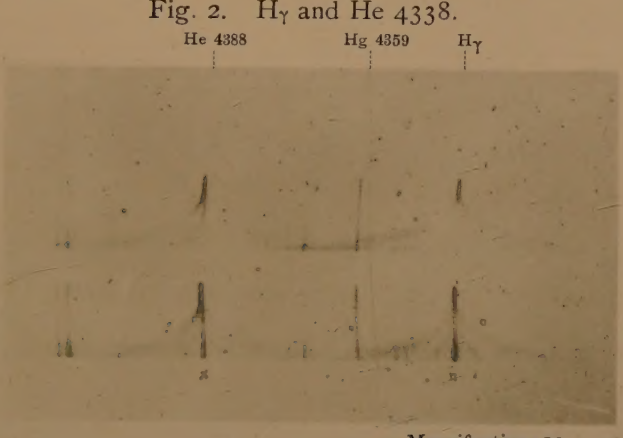
Fig. 1. Shift of the central s-comp. of H_γ.



$E_{max.}$: 130000 volt/cm.
Exposure: 1h 30m

Magnification: 16

Fig. 2. H_γ and He 4338.



$E_{max.}$: 113000 volt/cm
Exposure: 2h

Magnification: 13

Fig. 3a.
Fine resolution of H_α

Fig. 3b. do.

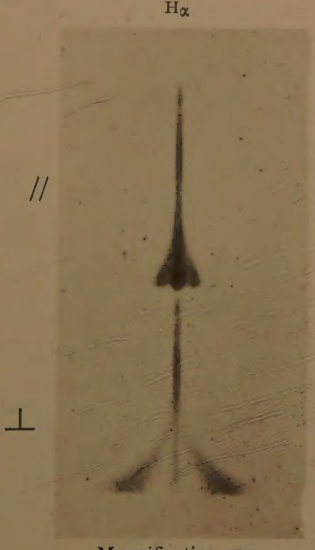


Fig. 3a.
$E_{max.}$: 69000 volt/cm.
Exposure: 4h

Fig. 3b.
$E_{max.}$: 94000 volt/cm.
Exposure: 1h 50m

Magnification: 14

Magnification: 14

The Effect of an Electric Field on the Spectrum Lines of Helium.

PART III.

By

Toshio Takamine and Noboru Kokubu.

(Received July 12, 1918.)

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§ 1. As reported in our preceding paper[1] relating to the Stark effect on hydrogen lines, some improvements were made in the experimental method for increasing both the field intensity and the brightness of the source of light.

In addition to the prism spectrographs mentioned in our former paper, a 6 inch plane grating mounted in Littrow type, and provided with a photographic objective of 48 cm. focus, was employed for examining the red and yellow lines. The dispersion in the second order was about 18 Å per mm. at λ 6500 Å.

Further, in order to detect a very small displacement of the lines, an echelon grating of 10 plates made by Hilger was placed behind the collimator of a single prism spectrograph. The use of an echelon grating for examining the Stark effect was first described by Brunetti[2], with sketches illustrating the mode of electrical resolution of the helium lines 6678 and 5016.

Although our experiments using an echelon was only of a preliminary nature, one of the photographs thus obtained is reproduced in Fig. 1, Pl. IV. In this photograph, the lines 5016 and 4713 are seen slightly displaced, the sign of the displacement in the echelon photograms being opposite to that in the prismatic dispersion. The lines largely affected by an electric field appear very confused, but

1 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto., **3**, 271 (1919)

2 Brunetti, Rendiconti d. Lincei, **24**, 55 (1915).

the method is useful to see whether, for a certain line, there is any influeuce of the electric field at all. For instance, we have examined the mercury lines 5461, 4359 and 4047, and also a group of strong lines in the red and yellow part of the neon spectrum. In both cases, we found that all these lines remain fairly sharp even in the strong field of over 50000 volt/cm. for mercury, and over 100000 volt/cm. for neon.

It may be worthy of note that the strong yellow line λ 5852 of neon remained perfectly sharp in such a high field. We think, the fact may be of significance in discussing the adequacy of choosing the this neon line as the standard in the accurate measurement of wavelengths.

It may be suggested that if we employ optical instruments possessing a high resolving power, we may perhaps find out the existence of a very weak field by means of the Stark effect. The exposure for obtaining a good echelon photogram needs not be long, in fact, the photograph reproduced in Fig. 1, Pl. IV was obtained with an exposure of only 10 minutes.

§ 2. In the summary of our previous investigation relating to the Stark effect on helium lines, we stated that:—

(I) There are three different ways in which helium lines are affected by an electric field, namely:

a) Symmetrical decomposition (λ 4686 line).

b) Non-symmetrical decomposition (Diffuse series lines of helium and parhelium).

c) One-sided displacement (Principal series of lines and sharp series lines of helium and parhelium). Of c), only the lines belonging to the principal series of parhelium are displaced toward the violet side, while the other three series lines are all displaced toward the red side.

In the present experiment, the maximum field strength was greatly increased. Assuming the proportionality between the field intensity and the amount of separation, the value of the maximum field, exterpolated from Stark's data, was about 150000 volt/cm.

Now, owing to the increased field strength, the lines 4121, 4438 and 3965, which have hitherto been said to be merely shifted by an electric field, were found to be resolved into a number of components, all being shifted in the same direction. For 4121 and 4438, we observed 2 *p*- and 2 *s*-components, and for 3965, 3 *p*- and 3 *s*-compo-

nents. The photograph showing the fine resolution of the line 3965 is reproduced in Fig. 2, Pl. IV. It seems very likely that the other lines belonging to the principal and sharp series of helium and parhelium may, if examined under a greater dispersion, be resolved into a greater number of components.

The helium lines newly examined in the present experiment were 6678, 5876, 4713, 3889 and 3188. Including the lines examined by one of us with Mr. Yoshida[1] which are marked by asterisks, and also those reported in our second communication[2], the Stark effect on the following 26 lines have been investigated in all.

6678, 5876, 5048*, 5016*, 4922*, 4713, 4686*, (4518*), 4472*, 4438*, 4388*, 4169, 4144, 4121*, (4046), 4026, **4009**, 3965, **3889**, **3868**, (**3830**), 3820, 3614, **3448**, **3188**, **2945**.

For the seven lines printed in gothic types in the above table, the Stark effect has not been observed by any of the former investigators such as Stark and Kirschbaum[3], Koch[4], Brunetti[5] and Nyquist[6]. The lines in brackets belong to the combination series first observed by Koch.

§ 3. As the result of closer examinations into the mode of separation, some alterations in the diagrams given in our previous communications became necessary.

In Pl. I, the lines are arranged according to the series relations. As will be seen, the peculiar mode of each series described in our previous paper has been confirmed in all the newly-examined lines.

In Pl. II, the mode of decomposition of various helium lines are illustrated. Here, the intensity of each component is roughly represented by its breadth in the diagram.

By aid of the grating spectrograph, the red line 6678 was found to be displaced toward the red side; and by aid of the echelon photograms the yellow line 5876 (D_3) was found to be displaced toward the violet side.

For both of the lines 5876 and 4472, a faint accompanying line

1 Takamine and Yoshida, Mem. Coll. of Sci., Kyoto. **2**, 325 (1917).
2 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).
3 Stark and Kirschbaum, Ann. d. Phys., **43**, 1017 (1914).
4 Koch, Ann. d. Phys., **48**, 98 (1915).
5 Brunetti, Rendiconti d. Lincei, **23**, 719 (1914); **24**, 55 (1915).
6 Nyquist, Phys. Rev., **10**, 226 (1917).

constituting a doublet with the main line was observed in the echelon photograms. Although the behaviour of these faint lines was difficult to be observed in detail, they seemed to be affected in nearly the same way as the central component of the main line.

§ 4. In glancing at the results hitherto obtained, the following features come to our notice.

a) The Isolated Components.

In the first report communicated by one of us, together with Mr. Yoshida[1], the appearance of a component which is, so to speak, quite isolated from the main line, was noted for the lines 4922, 4472 and 4388. In the second experiment[2], the same feature was found to be common to all the lines belonging to the diffuse series lines of helium and parhelium. In Fig. 4, Pl. V, a photograph showing the isolated component of the line 4922 is reproduced.

In the present experiment, a closer examination revealed that, in such cases, there are generally more than one isolated component, just as stated by Nyquist[3]. Referring to the isolated component which is far removed from the main line, we notice that its starting point approaches nearer and nearer to the main line as the term number in a series is increased.

One remarkable feature observed in the present experiment is that, for the lines 4388 and 4026, an isolated component which appears first on the immediate violet side of the initial line is shifted toward the red side as the field strength is increased, and finally, at the strong field over 120000 volt/cm. it even comes out on the red side of the initial line. It is especially noteworthy that, in the case of 4026, the strong *s*-component which first appears on the immediate violet side of the main line is seen to cross through another component. A brief account of this interesting phenomenon has already been noted in our second report[4], stating that a curious discontinuity is seen in 4026. At that time, however, the real feature was not revealed owing to the weak field.

Quite a similar phenomenon of the birth of a new component was observed by Paschen and Back[5] for the line 4388 when studying

1 Takamine and Yoshida, Mem. Coll. of Sci., Kyoto, **2**, 325 (1917).
2 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).
3 Nyquist, loc. cit.
4 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).
5 Paschen and Back, Ann. d. Phys., **39**, 897 (1912).

the Zeeman effect. According to them, the position of this new satellite is -0.5 Å, measured from the initial line. It is remarkable that this position almost coincides with the starting point of one of the isolated components observed in the present experiment.

b) *Intensity Variation of the Components.*

Generally speaking, the intensity of the components increases with the field strength. A notable exception is observed in one of the violet components of the line 4388, and also that of 4144, which fades away as the field increases.

c) *Lines of Combination Series.*

Three of the lines belonging to the combination series first noted by Koch, namely λ 4518, 4046 and 3830, were observed in our experiments. As shown in Figs. 4, 5, Pl. V, they do not appear when there is no electric field. In this respect, they may be said to stand with the isolated component above mentioned. In the case of the isolated components, however, some of them can be traced almost up to the zero field, but the combination lines seem to appear at much stronger fields; in other words, the rate of increase of intensity with the field is much greater for the latter.

It may be remarked that, according to Mr. Yoshida's[1] paper dealing with the Stark effect on lithium lines, a line at λ 4148, belonging to the combination series, was found to possess similar properties. The fact that the combination series lines of this sort are excited only in strong electric fields may be counted as one of the distinctive features peculiar to the series.

d) *Similarity between* 4388, 4026 *and* H_γ.

In *a*) we have mentioned that in the *s* component of the line 4388, one line which appears precisely on the violet side of the initial lines, is shifted toward the red side and even reaches the opposite side of the initial line in every strong fields. A similar component is also seen for the line 4026.

When we compare these two lines with the hydrogen line H_γ, we are struck by the great similarity in the mode of electrical resolution of these three lines.

From the series relation we have:

---

1 Yoshida, Mem. Coll. of Sci., Kyoto, **3**, 161 (1918).

	Hydrogen (Balmer Series)	Helium (Diffuse Series)	Parhelium (Diffuse Series)
Term No. $n=5$	H_γ	4026	4388

The essential likeness in the Stark effect on these three lines consists in that :—

1. The central line in the *s*-component is almost the strongest line of all the components.
2. The said line is shifted toward the red side as the field strength is increased. The only difference in helium and hydrogen is that the said line shows a discontinuity at its starting point in the case of helium. The photograph showing the helium line 4026 reproduced in Fig. 3, Pl. IV.

The striking similarity in the Stark effect on the corresponding lines of helium and hydrogen seems to suggest some hidden links in the mechanism of emission from the atoms of these two elements.

Summary.

1. Including the results previously published in Part I and Part II, the Stark effect on the following 26 helium lines were examined in all.

6678, 5876, 5048, 5016, 4922, 4713, 4686, 4518, 4472, 4438, 4388, 4169, 4144, 4121, 4046, 4026, **4009**, 3965, **3889**, **3868**, **3830**, 3820, 3614, **3448**, **3188**, **2945**.

For the seven lines printed in gothic types in the above table the effect has not been observed by other investigators.

2. The lines 4438, 4121 and 3965, which have hitherto been said to be merely shifted by an electric field, were found to be resolved into a number of components, all being shifted in the same direction.

3. A striking similarity was noted in the Stark effect on 4388, 4026, and on the hydrogen line H_γ, in the following points :—

a) The central line in the *s* component is the strongest of all the components.

b) The said line is shifted toward the red as the field strength is increased.

4. Advantages of using an echelon grating for examining the Stark effect is discussed. The behaviour of the faint line accompanying 5876 and 4472 as analysed by an echelon grating is described.

In conclusion, the writers wish to express their thanks to Prof. Mizuno for the interest he has taken in their work.

HELIUM

Term number	Principal Series λ in Å.U.	//	⊥	Diffuse Series (I.N.S.) λ in Å.U.	//	⊥	Sharp Series (II.N.S.) λ in Å.U.	P-comp.	S.-comp.
3	3888.8			5876.2 (intensity 1) **5875.9** (intensity 10)			7066.0 (1) **7065.5** (5)		
4	3187.8			4471.9 (1) **4471.6** (6)			4713.5 (1) **4713.3** (3)		
5	2945.2			4026.5 (1) **4026.3** (5)			4121.1 (1) **4121.0** (3)		
6				3819.9 (1) **3819.8** (4)			3867.8 (1) **3867.6** (2)		
7				3705.3 (1) **3705.2** (3)					

E in 10⁴ volt/cm.

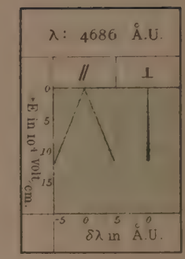
δλ in Å.U.

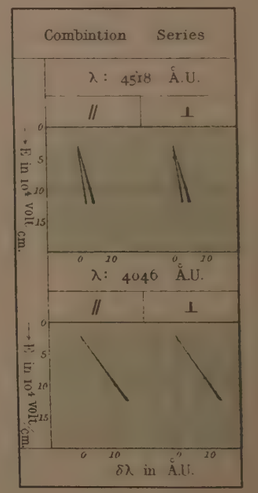
PARHELIUM

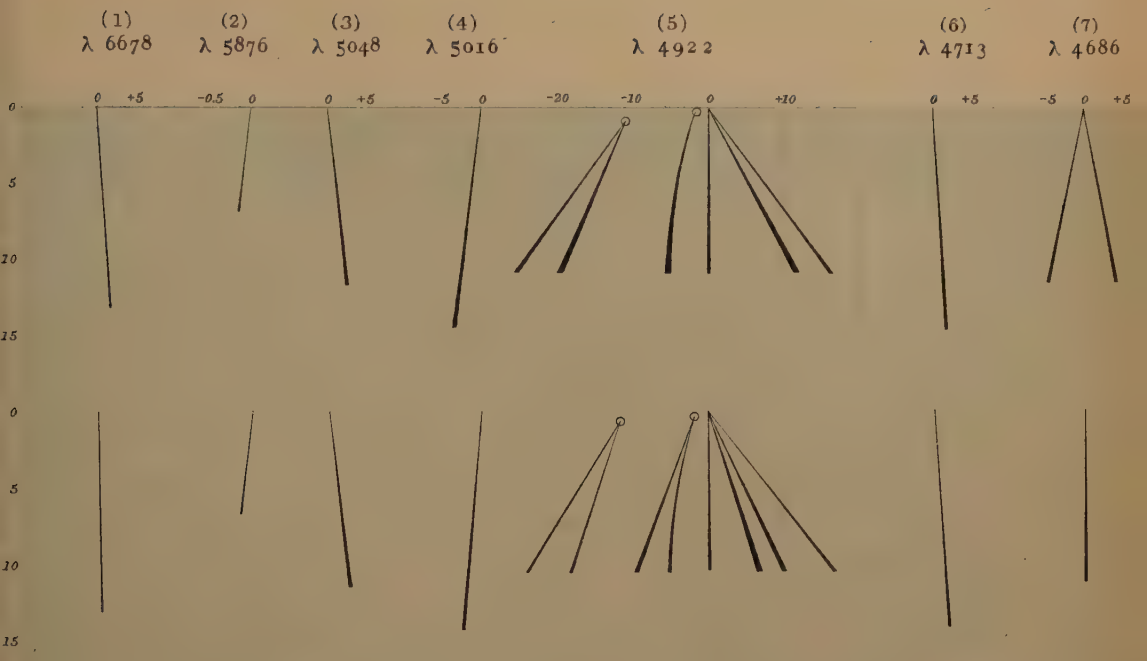
Term number	Principal Series λ in Å.U.	//	⊥	Diffuse Series I.N.S.) λ in Å.U.	//	⊥	Sharp Series (II. N.S.) λ in Å.U.	//	⊥
3	5015.7			6678.4			7281.8		
4	3964.9			4922.1			5047.8		
5	3613.9			4388.1			4437.7		
6	3447.7			4143.9			4169.1		
7				4009.4					

E in 10⁴ volt/cm.

δλ in Å.U.



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(4)
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(6)
λ 4713
(7)
λ 4686
0 +5
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0 +5
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-5 0 +5
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10
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0
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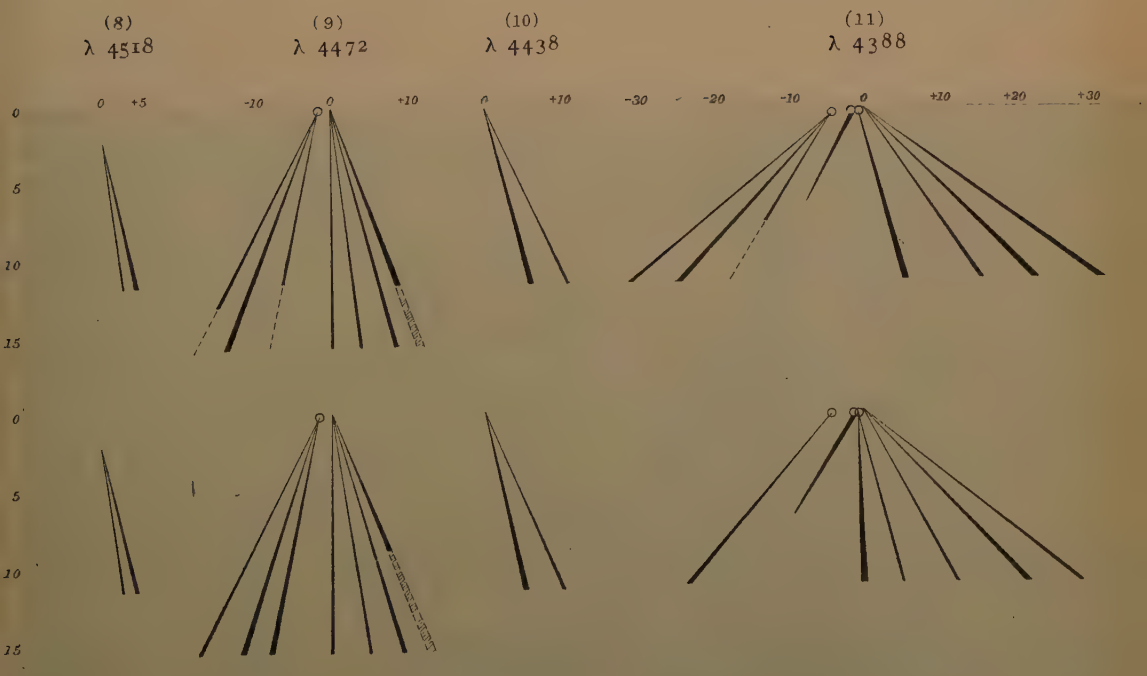
10
15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λ 4518
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λ 4438
(11)
λ 4388
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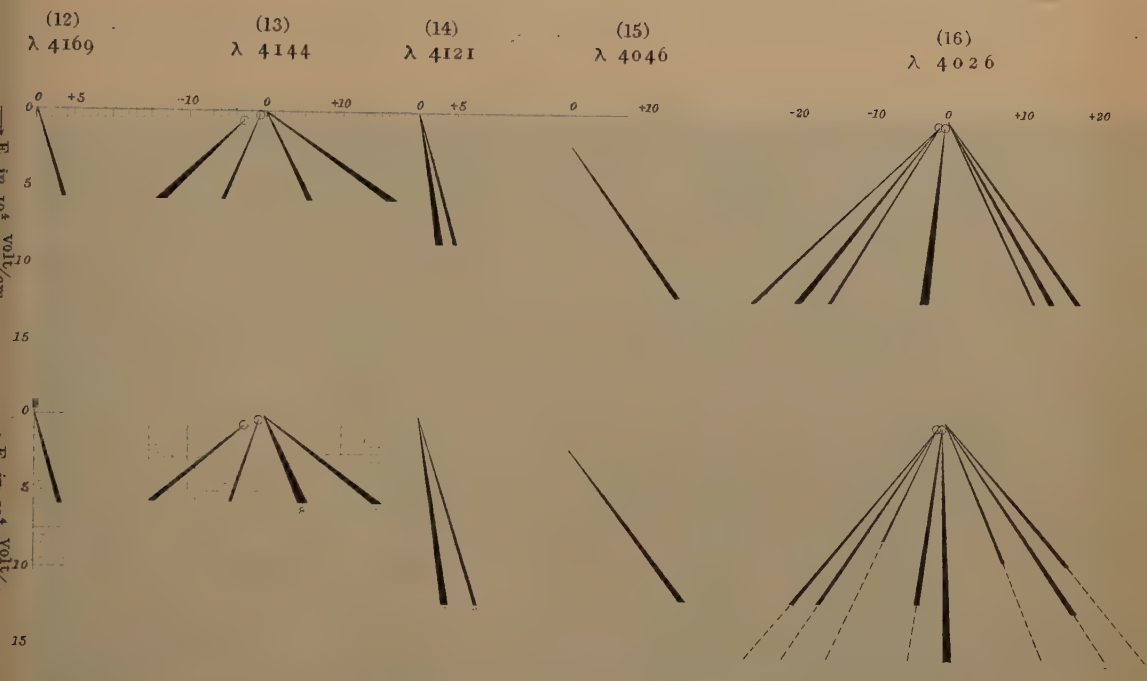
0
5
10
15
0
5
10
15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λ 4144
(14)
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(15)
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(16)
λ 4026
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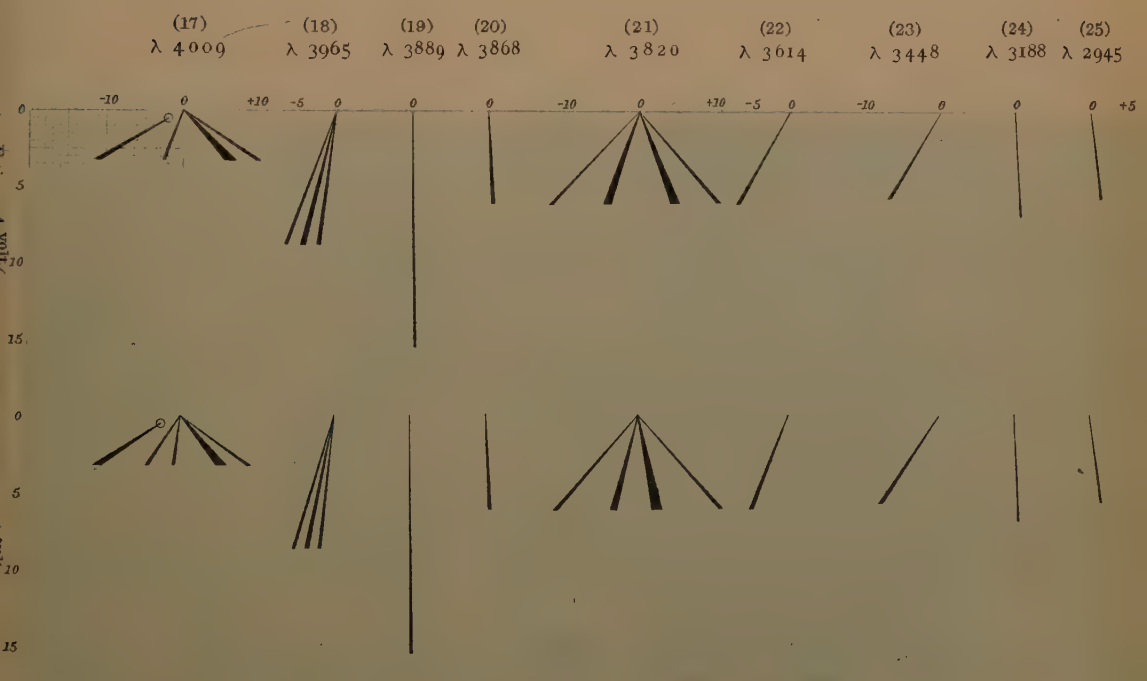
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λ 3614
(23)
λ 3448
(24)
λ 3188
(25)
λ 2945
0
-10
+10
-5
5
10
15

Fig. 1. The Stark Effect examined by an echelon grating

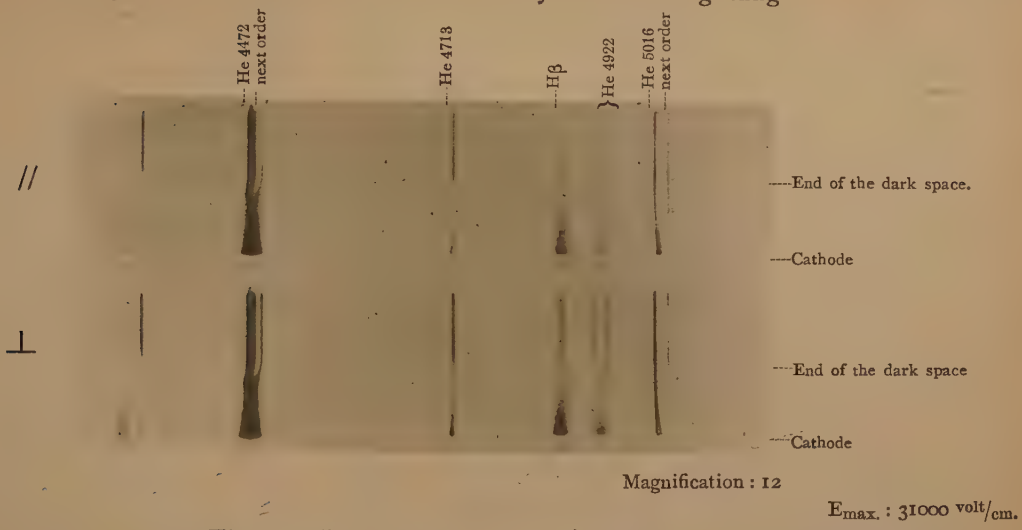


Fig. 2. Fine resolution of He λ 3965

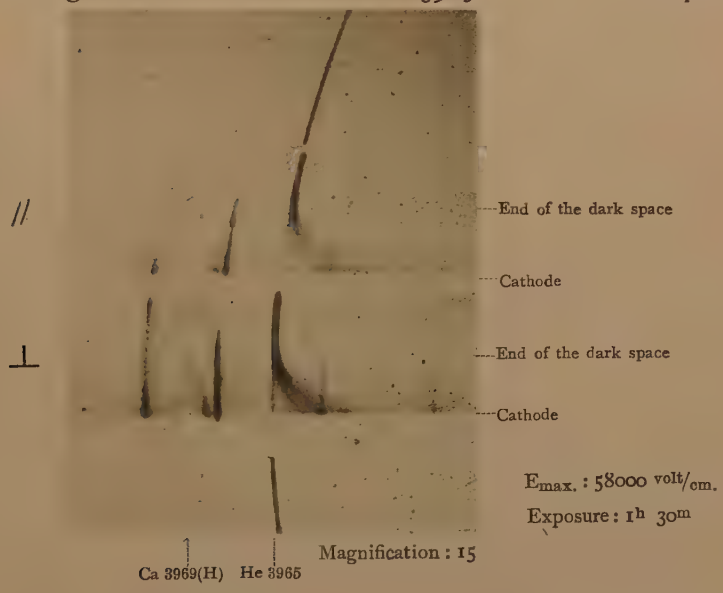


Fig. 3. He λ 4026

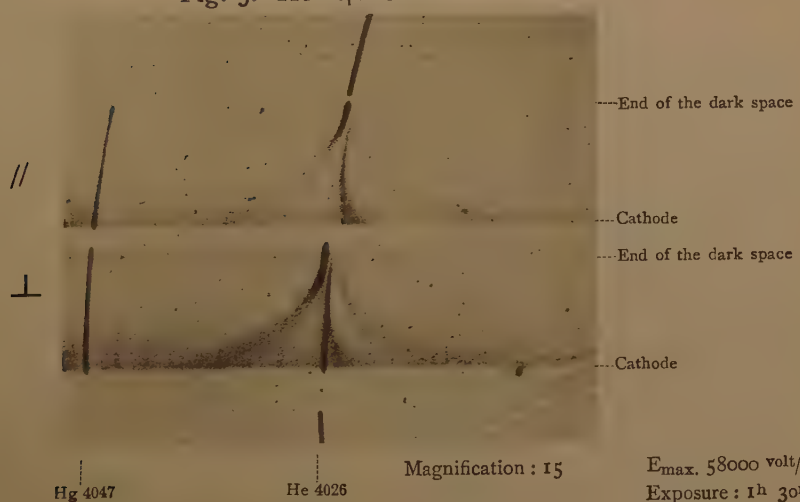
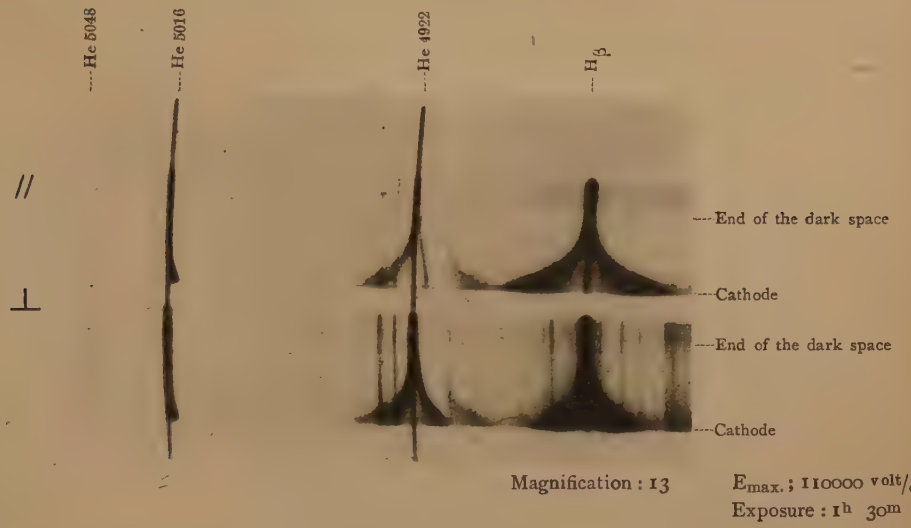


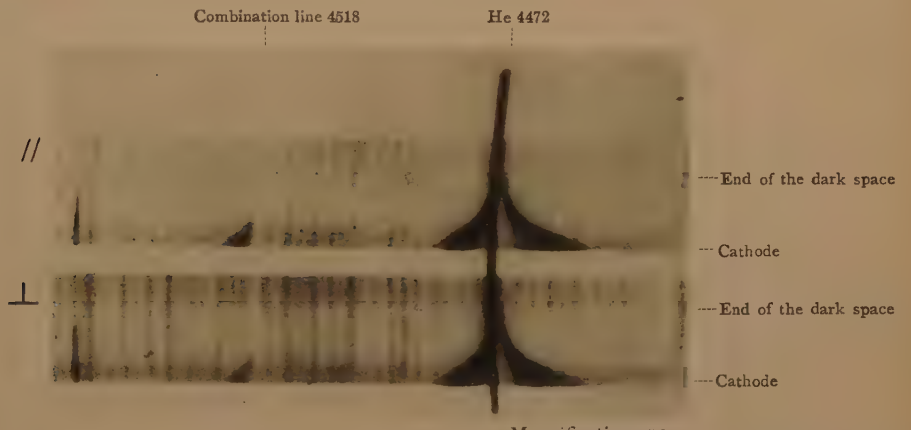
Fig. 4 (The isolated component of He 4922)



Magnification : 13

$E_{max.}$; 110000 volt/cm.
Exposure : 1^h 30^m

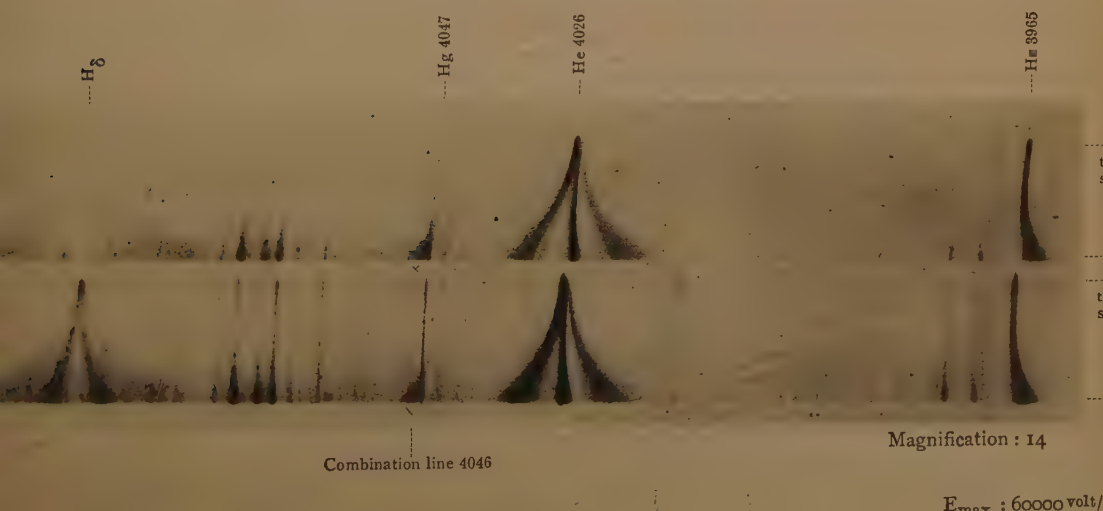
Fig. 5 (The combination line 4518)



Magnification : 13

$E_{max.}$: 110000 volt/cm.
Exposure : 1^h 30^m

Fig. 6 (The combination line 4046)



Magnification : 14

$E_{max.}$: 60000 volt/cm.

The Effect of an Electric Field on the Spectrum Lines of Argon.

By

Toshio Takamine and Noboru Kokubu.

(Received July 12, 1918).

On the Stark effect of the rare gases, helium was first studied by Stark[1] and others. Quite recently, Nyquist[2] has examined the effect in neon by modifying Lo Surdo's[3] method. So far as we are aware, the Stark effect on argon line has not hitherto been examined.

The experimental arrangement was quite the same as that reported in our previous paper[4] relating to the Stark effect on helium and hydrogen lines. The argon gas employed was that prepared by Hilger.

The Stark effect on argon lines is extremely small compared with that on helium and neon lines, and it was only after repeated experiments using very strong fields, that a group of lines in the violet region was found to be displaced toward the positive side. The numerical data for the affected lines are tabulated in Table I.

The field strength was calculated by using the data given by Stark for the " Grobzerlegung " of $H\beta$, thereby assuming that the proportion-

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1 Stark, Berl. Ber. Akad. d. Wiss., **47**, 932 (1913).

2 Nyquist, Phys. Rev., **10**, 226 (1917).

3 Lo Surdo, Rendiconti d. Lincei, **22**, 664 (1913).

4 Takamine and Yoshida, Mem. Coll. of Sci., Kyoto, **2**, 137, 321, 325 (1917).

5 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).

triply charged, while the diffuse series lines are said to be doubly charged, so that the above results appear somewhat contradictory. As, however, in the first report, Stark and others[1] have denoted the line 4339 as singly-charged, the question of the multiplicity of the charge may be said to be somewhat ambiguous for this line.

As to the series relations in the mercury spectrum, Wiedmann[2] has denoted the following groups as belonging to the diffuse single line series and its combinations.

$$m = 3 \begin{cases} 5791 \\ 5790 \\ 5769 \end{cases} \qquad m = 4 \begin{cases} 4349 \\ 4343 \\ 4339 \end{cases}$$

In one of the echelon photograms, a tendency of the red-side displacement was noticed for the line 5769, which corresponds to λ 4339 in the consecutive term number.

It may be remarked that no series relation has been established in the argon spectrum, but groups of lines having constant frequency differences were found by Rydberg[3] and also by Paulson[4] in the "red spectrum." For the sake of convenience, the classification of Rydberg is given in our Table I for each affected line.

Summary.

1. Employing Lo Surdo's method, the Stark effect on the spectrum lines of argon has been examined, and the following sixteen lines were found to be slightly displaced toward the red in strong electric field:

4933.5, 4510.9, 4335.4, 4333.7, 4300.2, 4272.3, 4259.5, 4200.8, 4198.4, 4191.0, 4182.0, 4164.4, 4158.7, 4153.0, 4132.0, 4046.0.

The greatest field strength exterpolated by using Stark's data was about 170000 volt/cm.

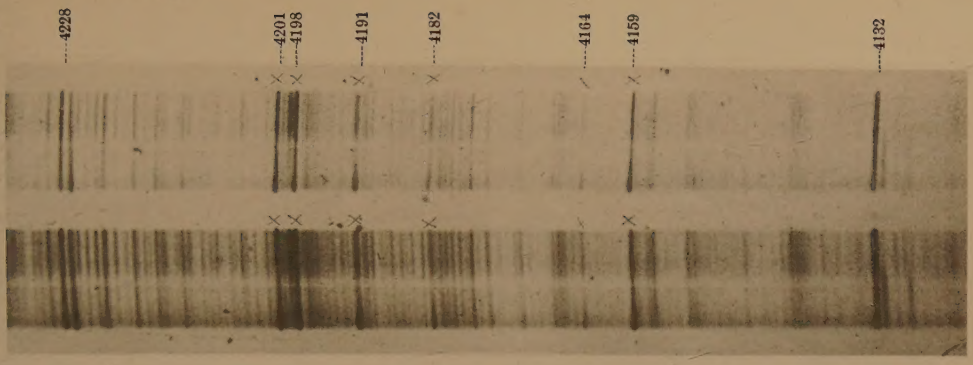
2. It is remarkable that almost all the affected lines belong to the "red spectrum" of argon. Thus, so far as the present experiment is concerned, the so-called arc lines seem to be more easily affected by an electric field than the spark lines. This is also in comformity with our former results relating to the Stark effect on the lines of He, Ca and Mg.

1 Stark, Hermann and Kinoshita, Ann. d. Phys., **21**, 462 (1906).
2 Wiedmann, Ann. d. Phys., **38**, 1014 (1913).
3 Rydberg, Astrophys, J., **6**, 338 (1897).
4 Paulson, Phys. ZS., **15**, 831 (1914).

3. Beside the argon lines, a mercury line 4339 was found to be displaced about 0.7 Å for the *p*-comp. and 0.5 Å for the *s*-comp. toward the red in the field of 53000 volt/cm.

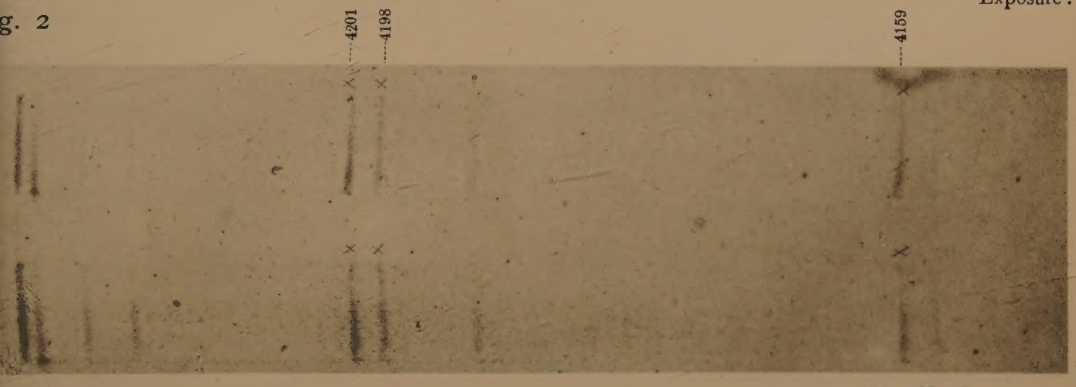
In conclusion, the writers wish to express their thanks to Prof Mizuno for the interest he has taken in their work.

g. 1

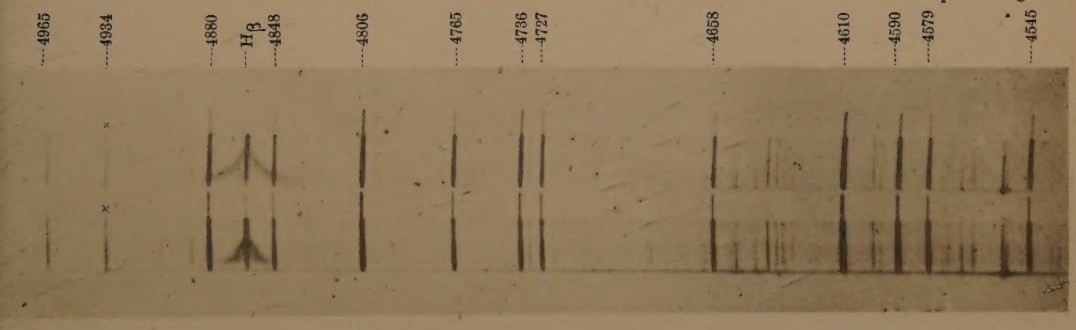


Magnification : 16 $E_{max.}$: 105000 volt/
Exposure : 3h

g. 2

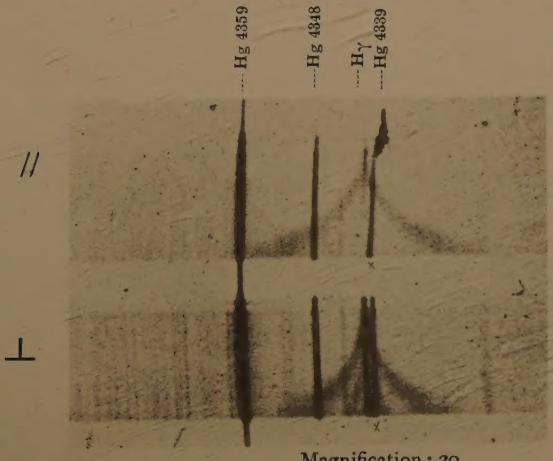


Magnification : 20
$E_{max.}$: 170000 volt/cm
Exposure : 3h



Magnification : 10
$E_{max.}$: 170000 volt/cm.
Exposure : 3h

The Stark Effect
Mercury Lines



$E_{max.}$: 53000 volt/cm.
Exposure : 1h

Magnification : 20

Vol. III, No. 9, Published March 30th, 1919.

Price - - - Yen 1.00

These Memoirs are on sale at

MARUZEN COMPANY, LTD.

TOKYO, OSAKA, KYOTO, FUKUOKA & SENDAI.

大正八年三月二十七日印刷

大正八年三月三十日發行

編纂兼發行者　京都帝國大學理科大學

印刷者　大久保秀次郎

東京府北豐島郡巢鴨町三丁目十番地

印刷所　株式會社　東京築地活版製造所

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